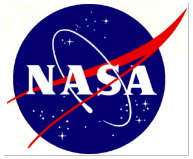


Tribology & Mechanical Components Branch Overview

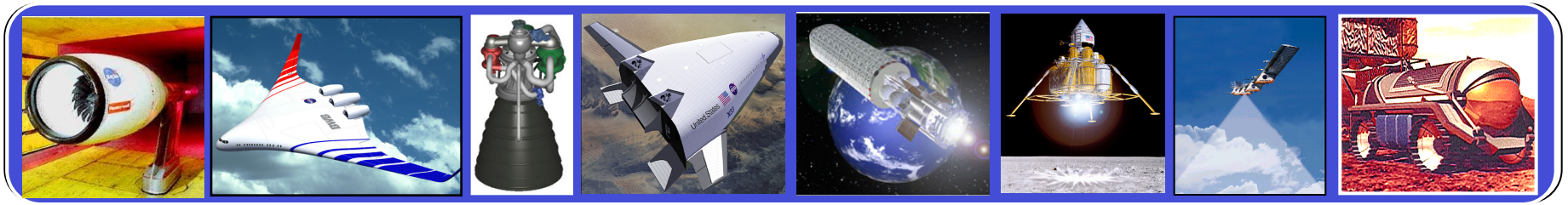
James J. Zakrajsek
Dr. Robert F. Handschuh
NASA Glenn Research Center
Cleveland, Ohio, U.S.A.

Topics

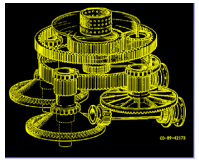
- View from 30,000 feet
- Structures and Materials Division
- Tribology & Mechanical Components Branch
- Drive system activities
- Summary

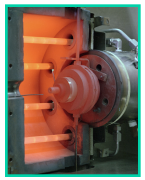
NASA Glenn Research Center

Materials and Structures Division

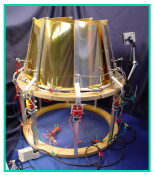


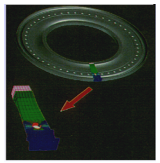
Propulsion and Power System Components

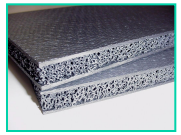


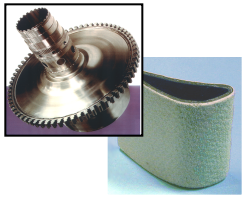


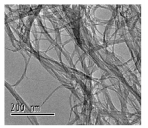
- Aeroshells
- TPS; Cooled strs.
- Cryogenic tanks
- Nacelles
- Combustors
- Engine fan system
- Mechanisms
- Oil-Free engines
- Injectors
- High-power motors
- Space lubricants
- Protective Coatings
- Sensors
- Thermoelectrics
- Surface mobility systems
- Nozzles
- In-space & on-surface modules
- Rotor discs and systems
- Turbine vanes
- Energy absorbing systems
- Mechanical drive systems
- Human health systems
- Thrusters
- Bearings and flywheels
- Solid oxide fuel cells, batteries
- High temp. and cryogenic seals
- Porous membranes
- BN nanotubes









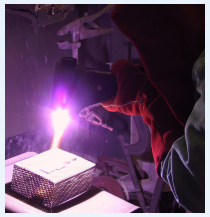


Core R&T Capabilities

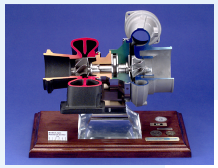
- Probabilistic methods
- Mechanical power transfer
- Impact dynamics
- Structural mechanics
- Material modeling
- Material characterization
- Functional materials
- Metallic alloys
- Computational materials
- Surface science
- Materials science
- Matl. and strl. Concepts
- Health prognostics
- Blast mechanics
- Structural dynamics
- Joining technology
- Failure and damage growth
- Processing technologies
- Shape memory alloys
- Protective coatings
- Extreme environment effects
- High temperature chemistry
- Design technology
- Experimental methods
- Measurement technology
- Aeroelasticity
- Durability and life
- Fatigue and fracture
- High temp. and cryo seals
- Ceramic materials
- Multifunctional Materials
- Lubricant chemistry
- Friction and wear

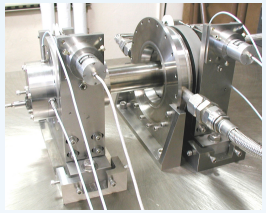
Tribology & Mechanical Components Branch

Advanced Bearing Technology



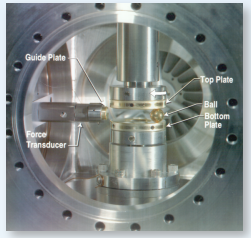
From basic research to application

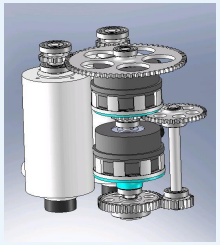




- Aero / Space application
- World-leading bearing experts
- Advanced modeling methods
- Foil bearing predictive design

Space Mechanisms & Lubrication

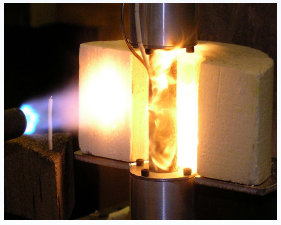


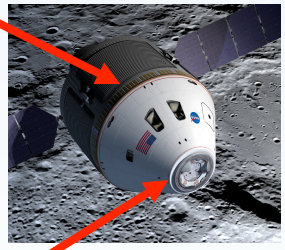


- Accelerated space lubricant life testing under vacuum
- New mechanism concepts for planetary environment
- New space lubricant development
- Terramechanics modeling & testing for efficient wheels

Aerospace Seals Research

Heat Shield Interface Seal

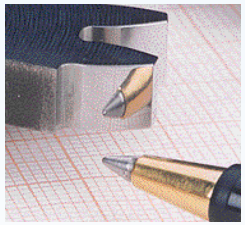


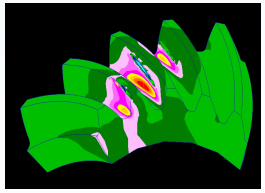


Docking Seal

- Space habitat seals for extreme environments
- Structural / thermal protection seals
- Non-contacting turbine seals

Aero Drive Systems





- Gear fatigue research
- High speed gear lubrication
- Drive system diagnostics
- Fatigue crack modeling
- Dynamic mechanical components
- Rotorcraft transmission systems
- Advanced rolling element and wave bearing technologies

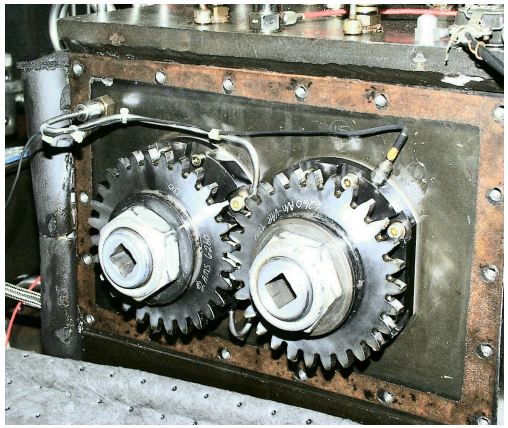
Tribology & Mechanical Components Branch

Branch Teams:

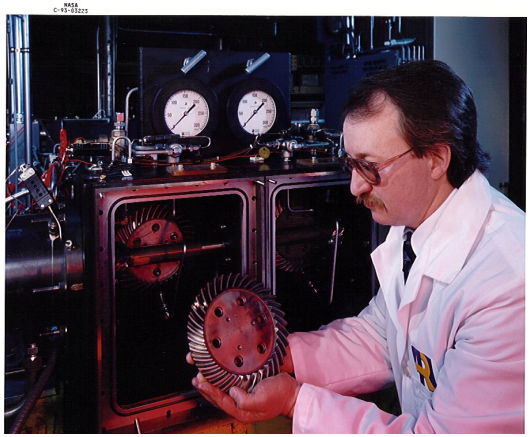
- **Advanced Bearings**
- **Space Mechanisms & Lubrication**
- **Aerospace Seals**
- **Aero Drive Systems**

Aero Drive System Team Mission **is to conduct basic research and technology on mechanical components and drive systems. Results lead to first principal understanding of complex phenomena of component or system operation in normal and extreme conditions. Technology transfer results in improved operation efficiency and safety of Subsonic Rotary Wing Aircraft.**

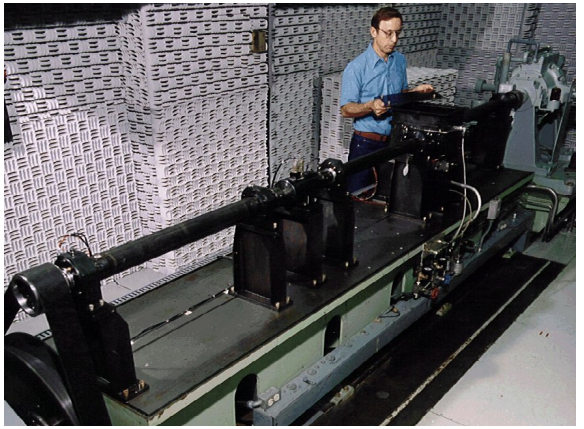
Drive System Legacy Test Facilities



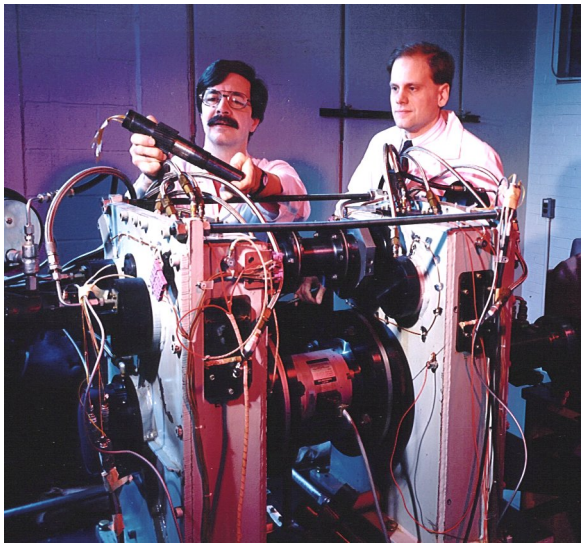
Spur Gear Fatigue Test Rigs



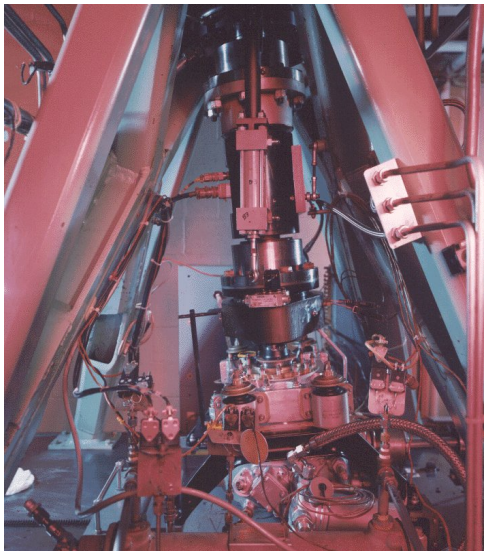
Spiral Bevel / Face Gear Test Facilities



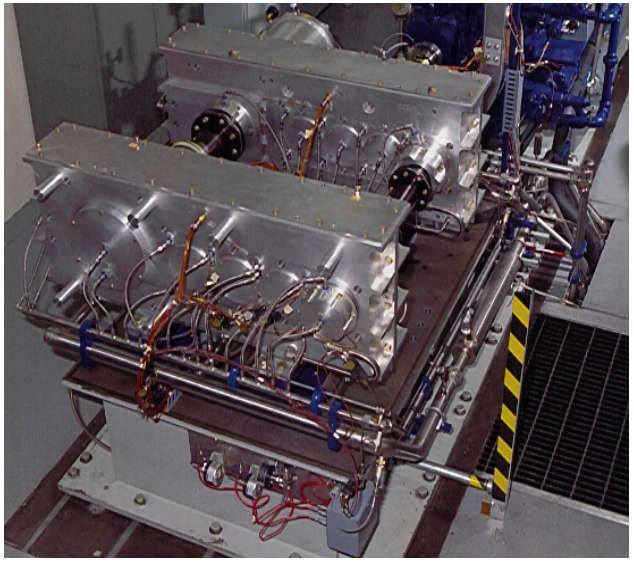
Gear Noise / Dynamics Test Facility



Split Torque Test Facility



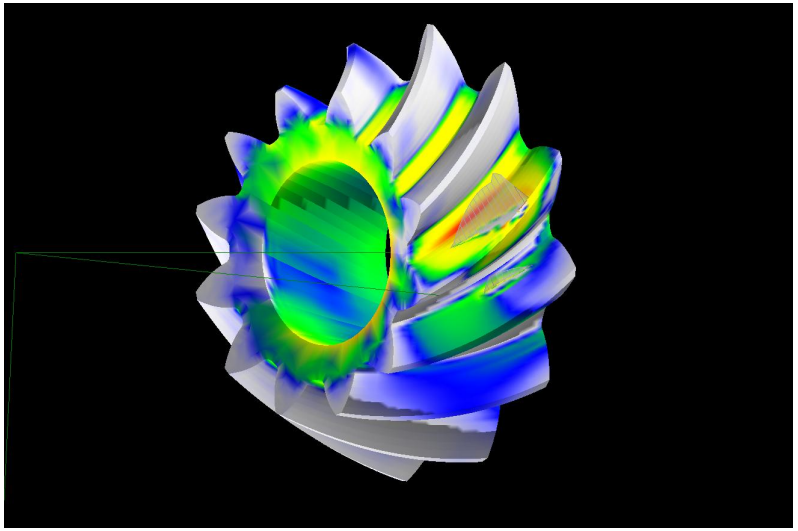
OH-58 Transmission Test Facility



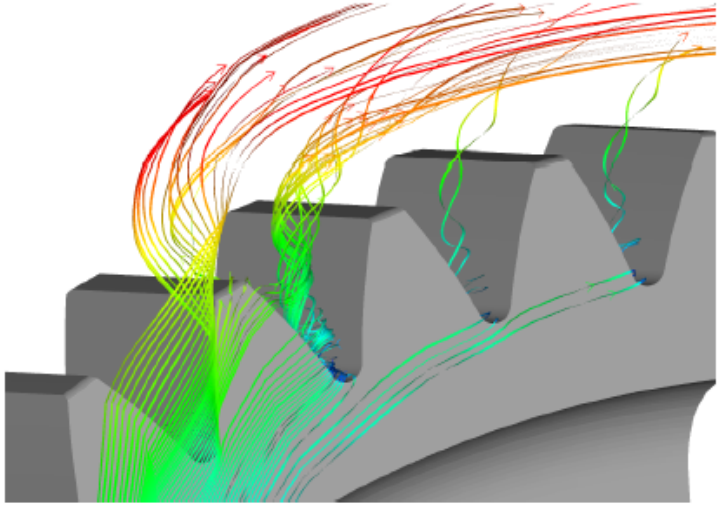
High Speed Helical Gear Train Facility

Drive System Analytical Capabilities

- **Finite element, boundary element, finite difference modeling used for structural and thermal analysis**
- **Condition based maintenance signal analysis tools**
- **Computational fluid dynamics analysis tools**



Finite Element Analysis of Spiral Bevel Gear



CFD Analysis of spur gear operating at high rotational speed.

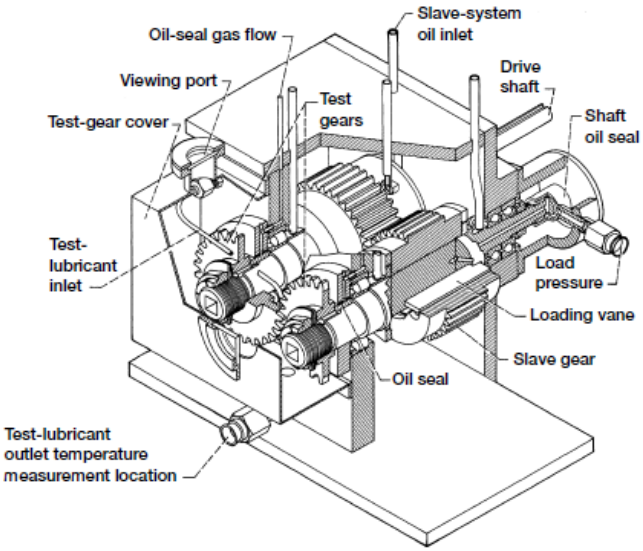
Technologies for Propulsion – Drive Systems

- **Advanced Drive System Components and Systems**
  - Multi / variable speed drives
  - Improved gear alloys
  - Enhanced gear operation / control
  - Composite material application to dynamic components
  - Non-traditional materials (Ni-based, ceramic,…)
  - Modified geometry gear design, bearings & system arrangements
  - High temperature operation of drive systems

- **Lubrication Technology**
  - Improved loss-of-lubrication (longer time, lighter weight,…)
  - Reduced power loss – windage drag reduction

- **Condition Based Maintenance – HUMS**
  - Improved detection techniques – i.e. non-metallic sensors
  - Improved data algorithms
  - Validated methods – rotorcraft field verification

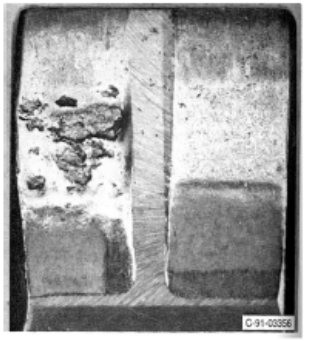
Gear Contact Fatigue Testing



Legacy Test Rig

New Test Facilities

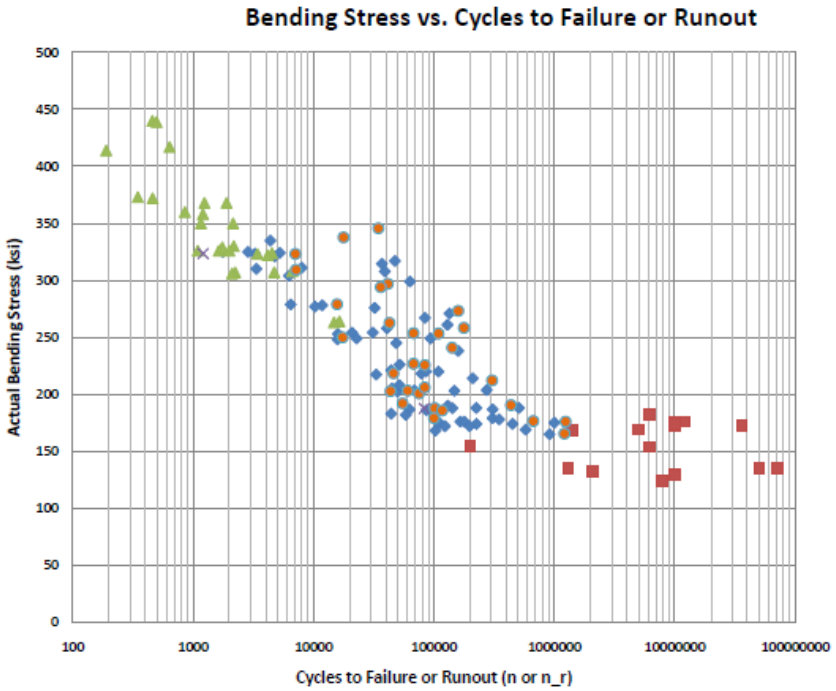
- Up to 10,000 rpm, 220+ ft·lb torque (new test rigs)
- Investigate effect of material, heat treatments, surface treatments, tooth profiles, contact ratio, lubricant chemistry, …….

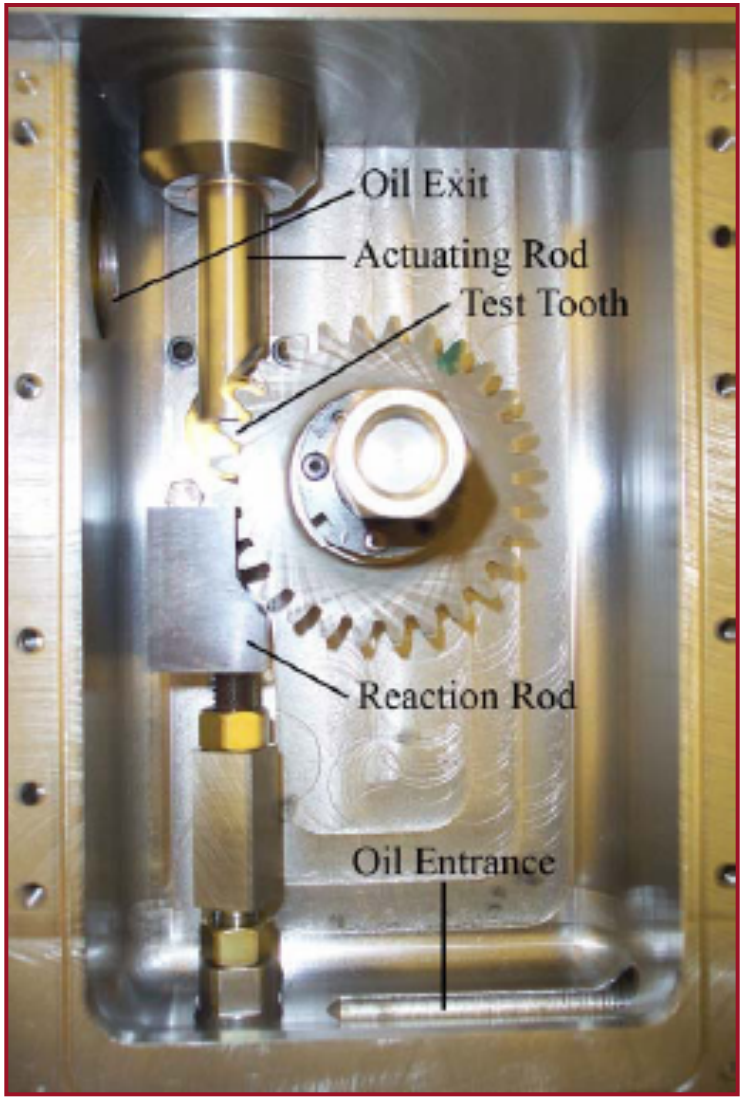


Example Test Gear

Single Tooth Bending Fatigue

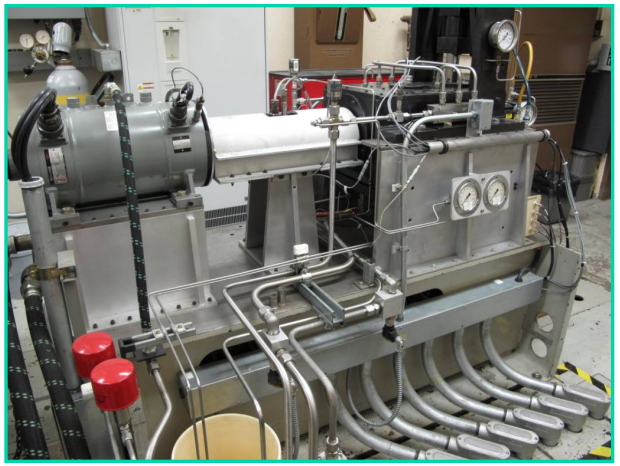
- Unique single tooth bending capability
- Operation up to 1000 Hz
- Heated – cooled test capability
- Conduct test without removing adjacent teeth

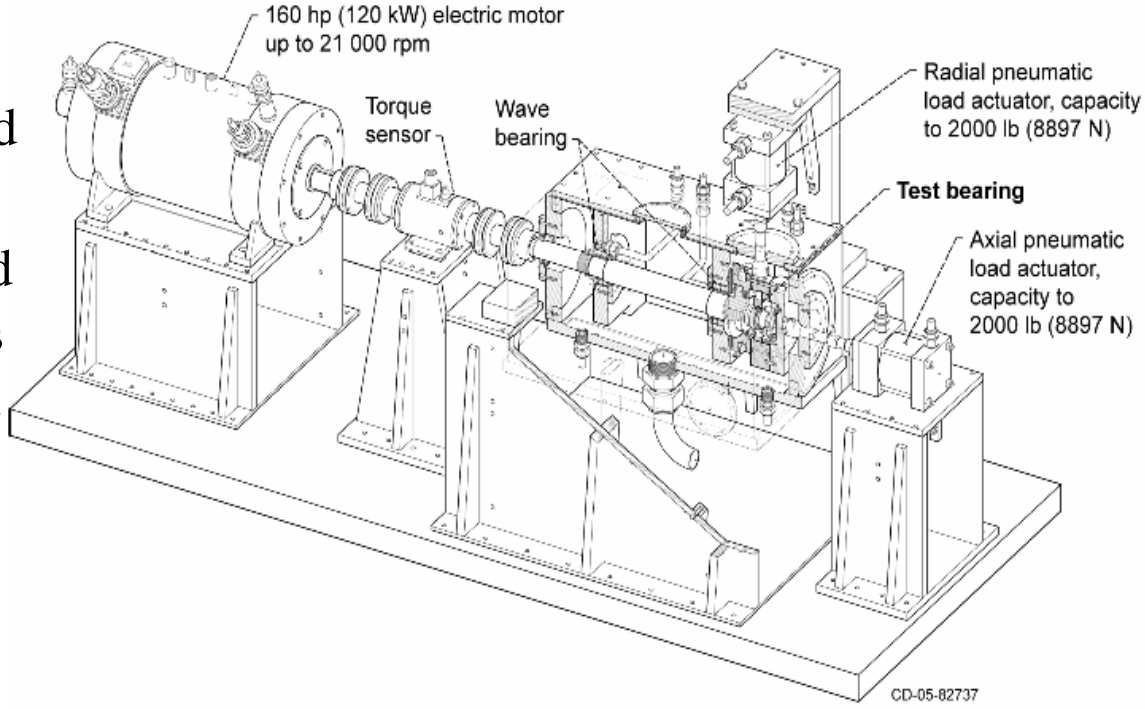




Hybrid Bearing Test Facility

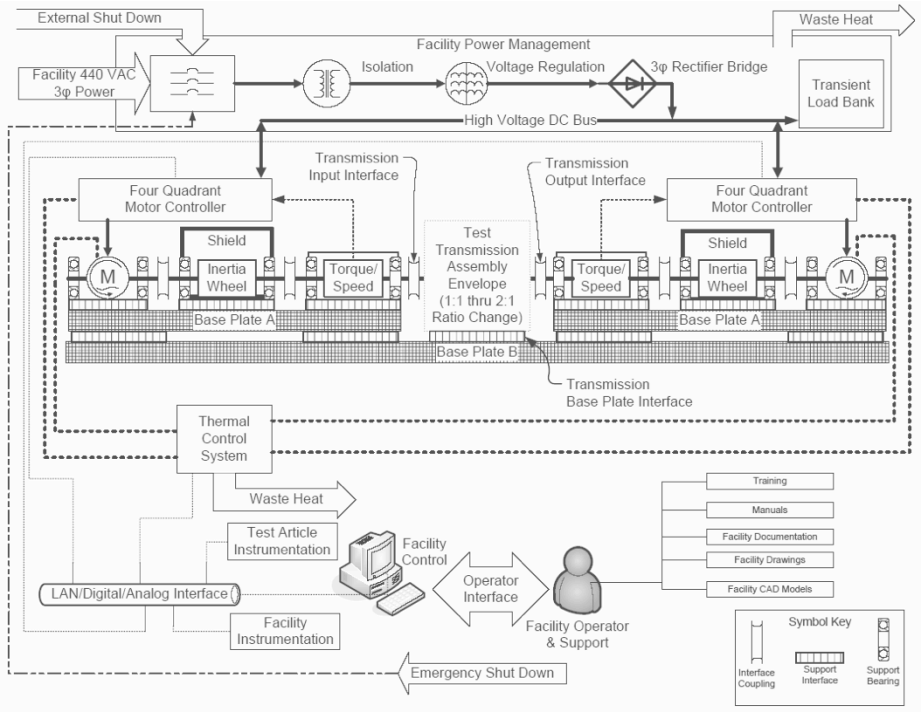
- 150 hp, 21,000 rpm motor
- Test bearing subjected to variable axial and radial loads
- Oil debris monitoring and vibration instrumentation
- Test bearing isolated from drive-train vibration by fluid film bearings
- Near term to conduct hybrid bearing fatigue experiments and diagnostics, data fusion





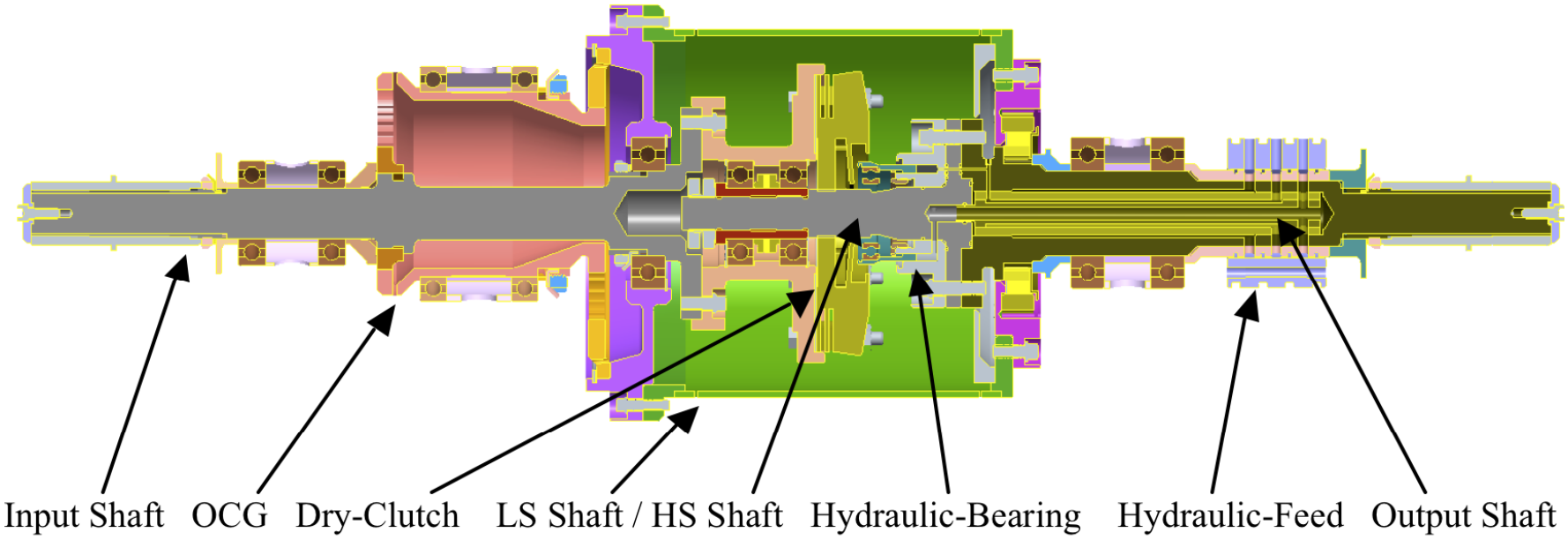
Variable / Multi-speed Test Facility

- 1 input, 1 output, each 250 hp and 15,000 rpm maximum
- Concepts for variable/multi-speed drive developed and down-selected, then tested in this facility
- Positive feedback from industry on variable speed drive-train technologies for rotorcraft



Multi-Speed Concepts

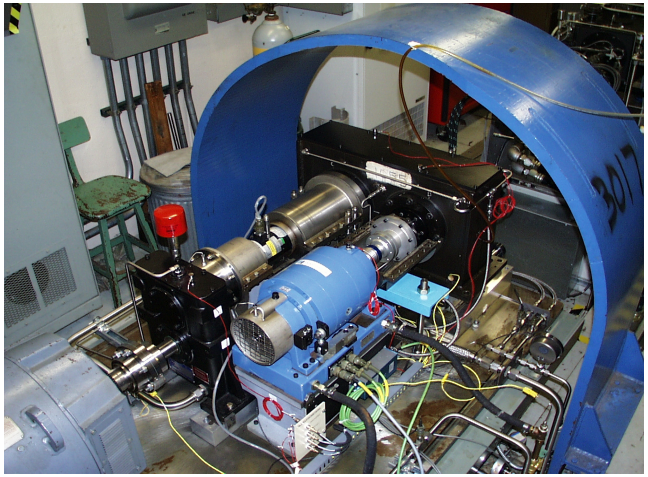
Offset Compound Gear Drive with Dry Clutch

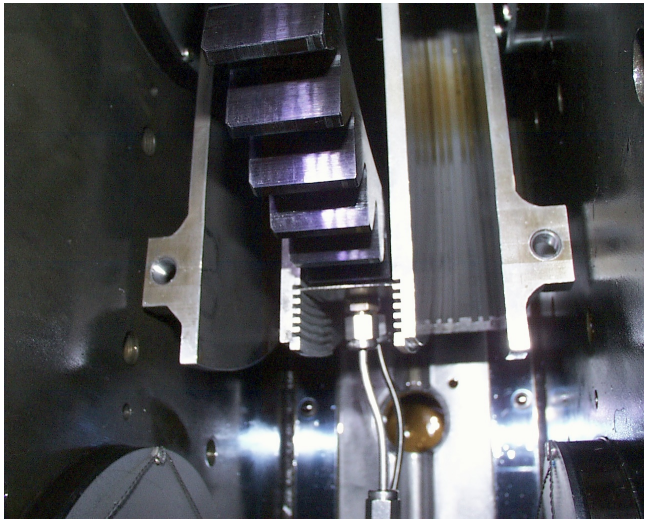


Two gear drive arrangements: Offset Compound Gear Drive and Dual Star Idler Planetary

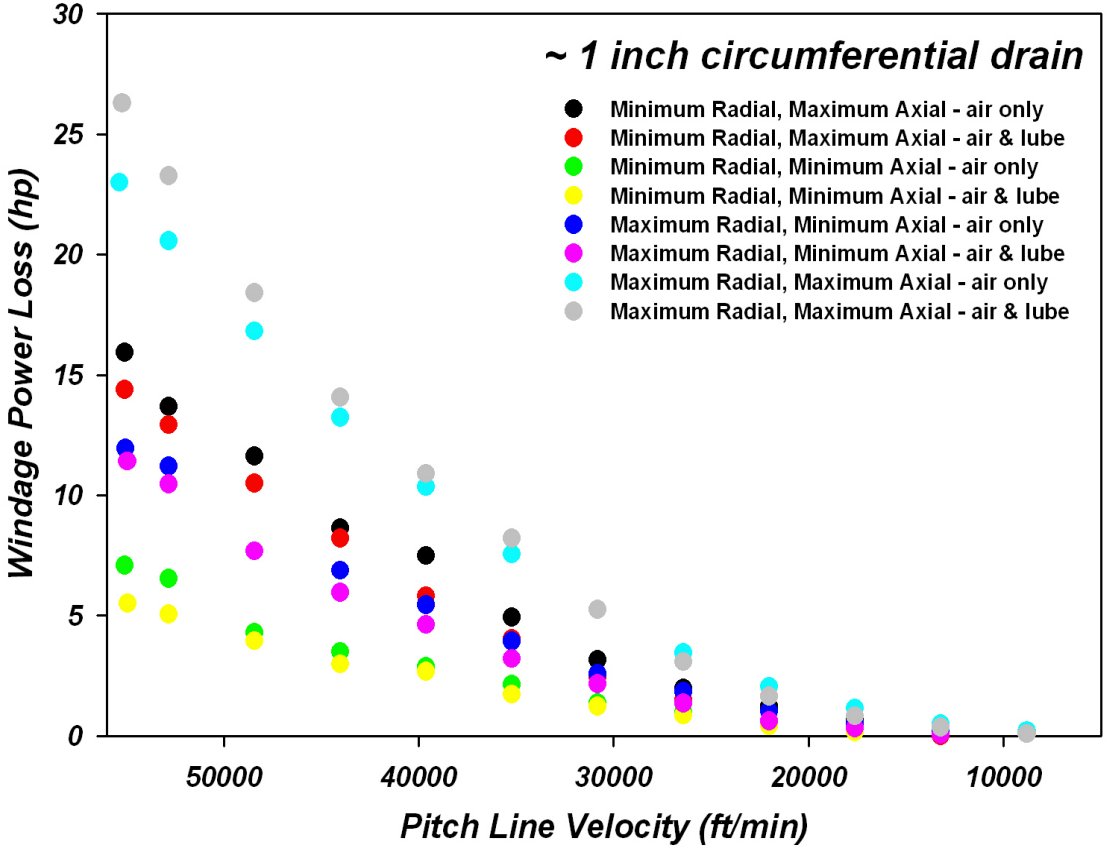
Two clutch configurations: Dry and Wet Clutch

NASA Windage Test Results



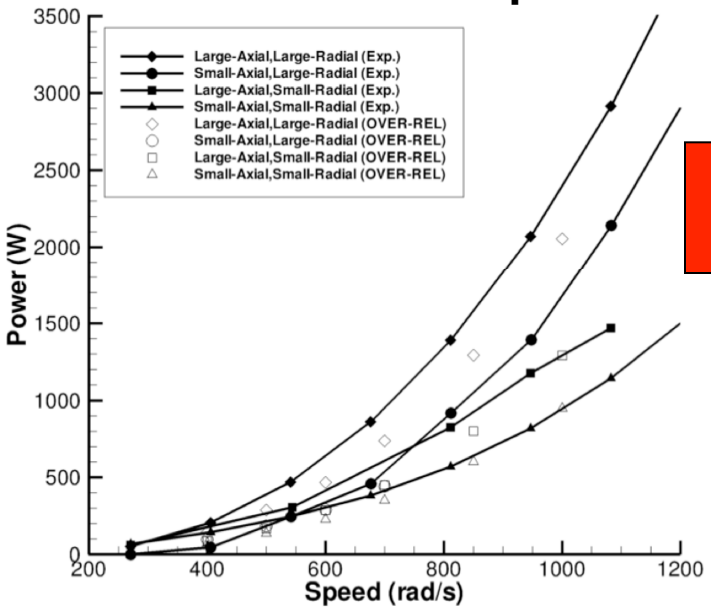


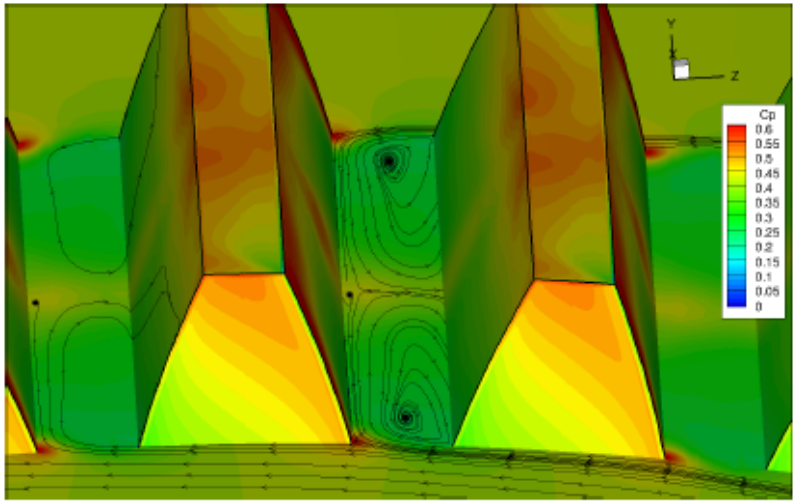
Single Gear Test Results
(13 inch pitch diameter gear)



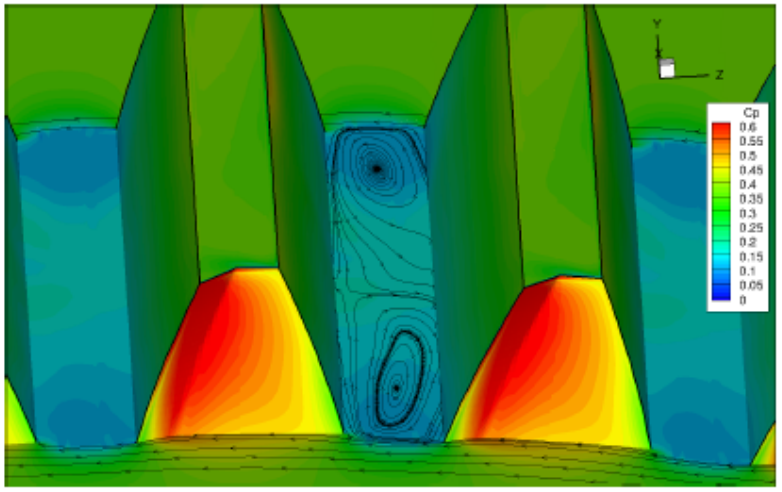
Penn State University Analysis Comparison (NRA)

PSU Analysis to NASA Results Comparison

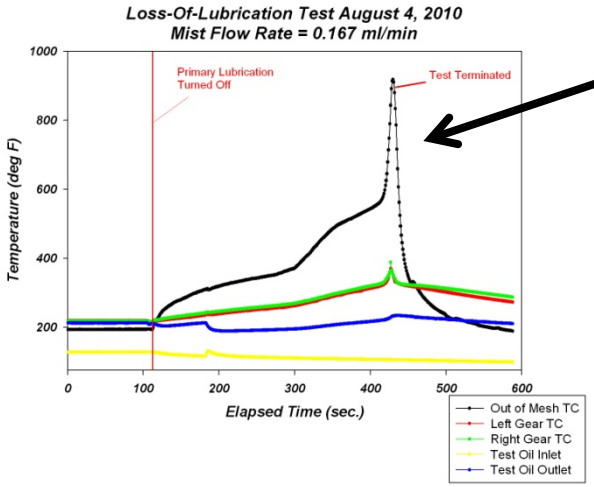




Possible Performance Improvement - Trailing Surface Ramp

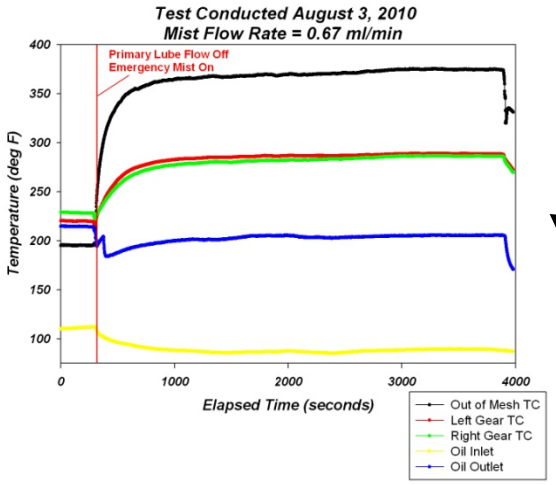


NASA GRC Loss of Lubrication Evaluation



Failed 6 minutes

Post-Test: Gear that failed



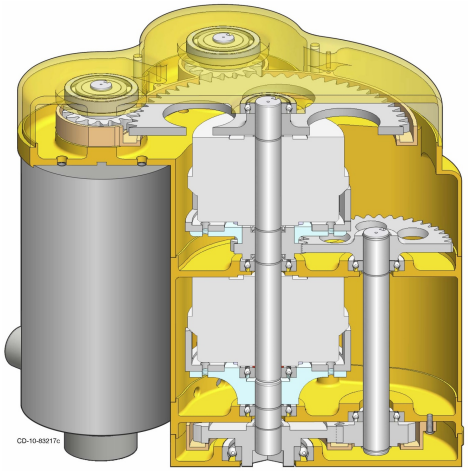
Successful operation
> 1 hour

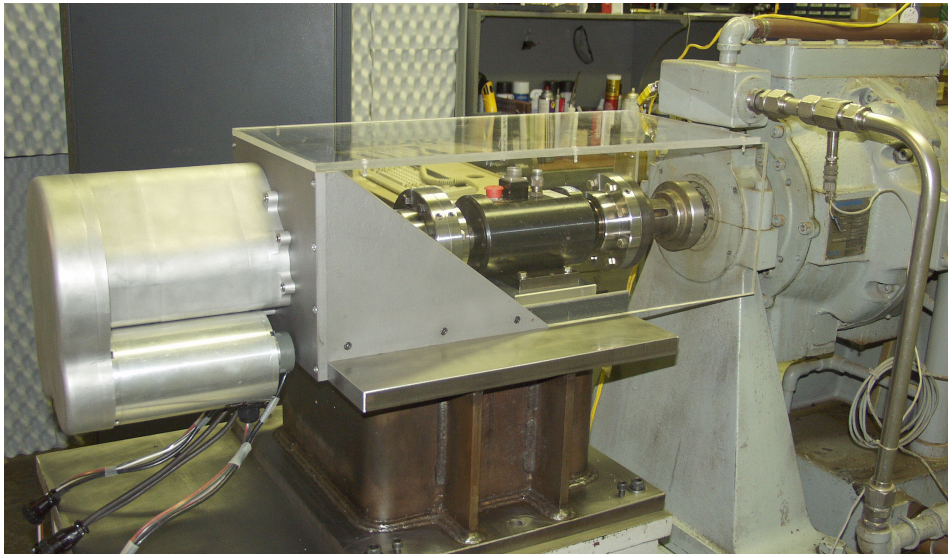
3x increase in mist flow rate

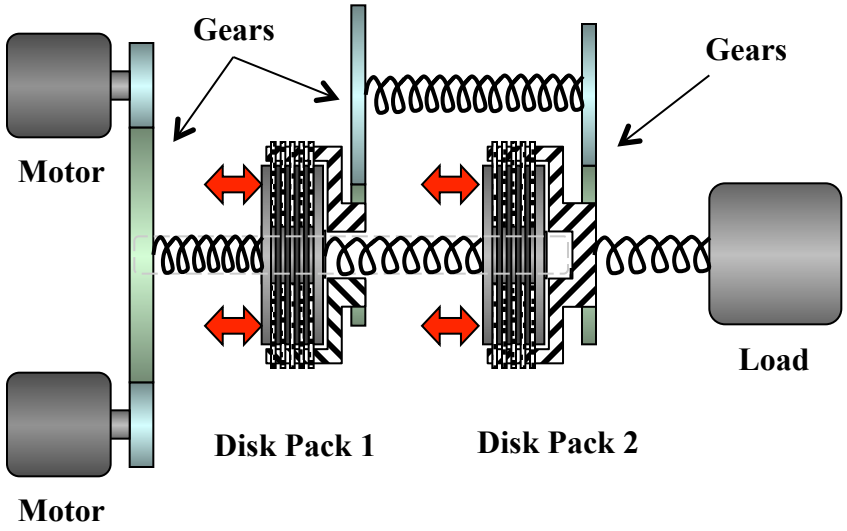
Two-Speed Gearbox Dynamics

Objective/Approach:

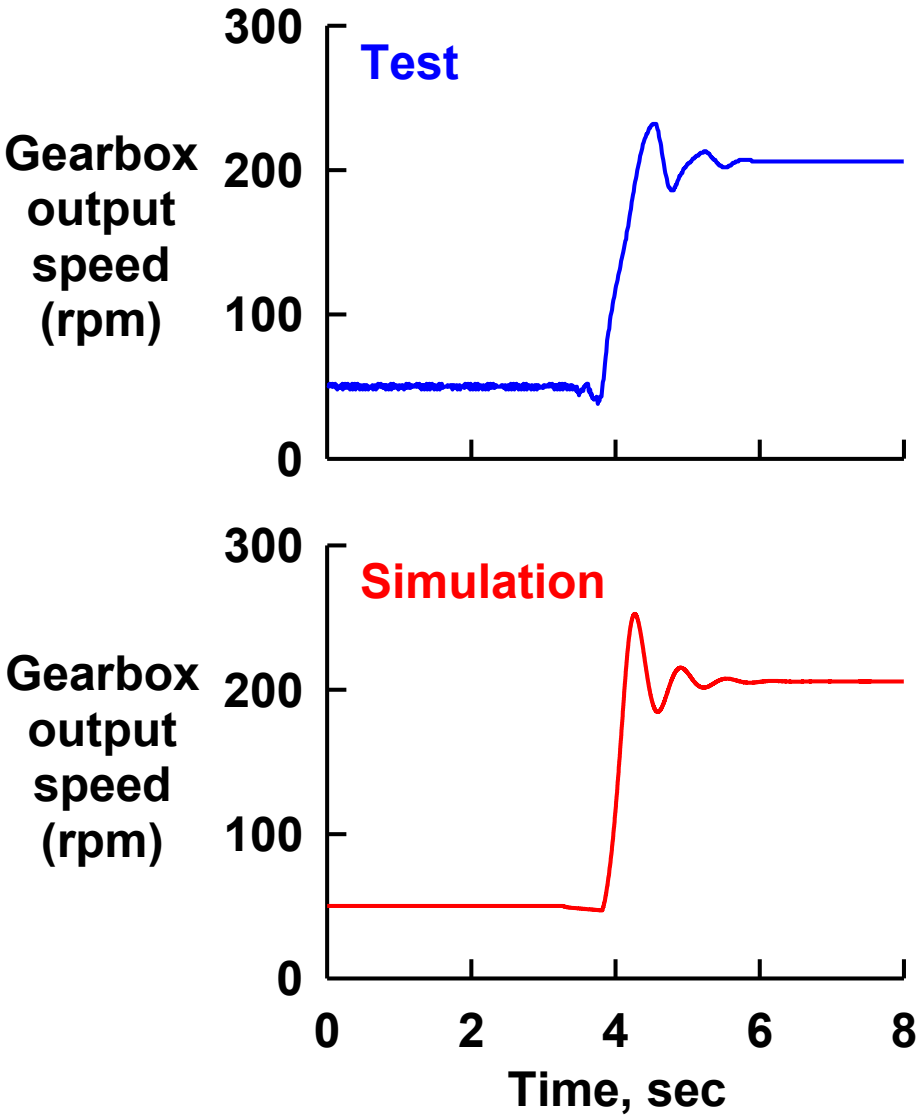
- Validate gearbox dynamic model
- Model developed at Penn State University NRA, two-speed Chariot gearbox modeled.
- Experimental tests performed on Chariot gearbox
- Dynamics during up-shift and down-shift measured and compared to predictions

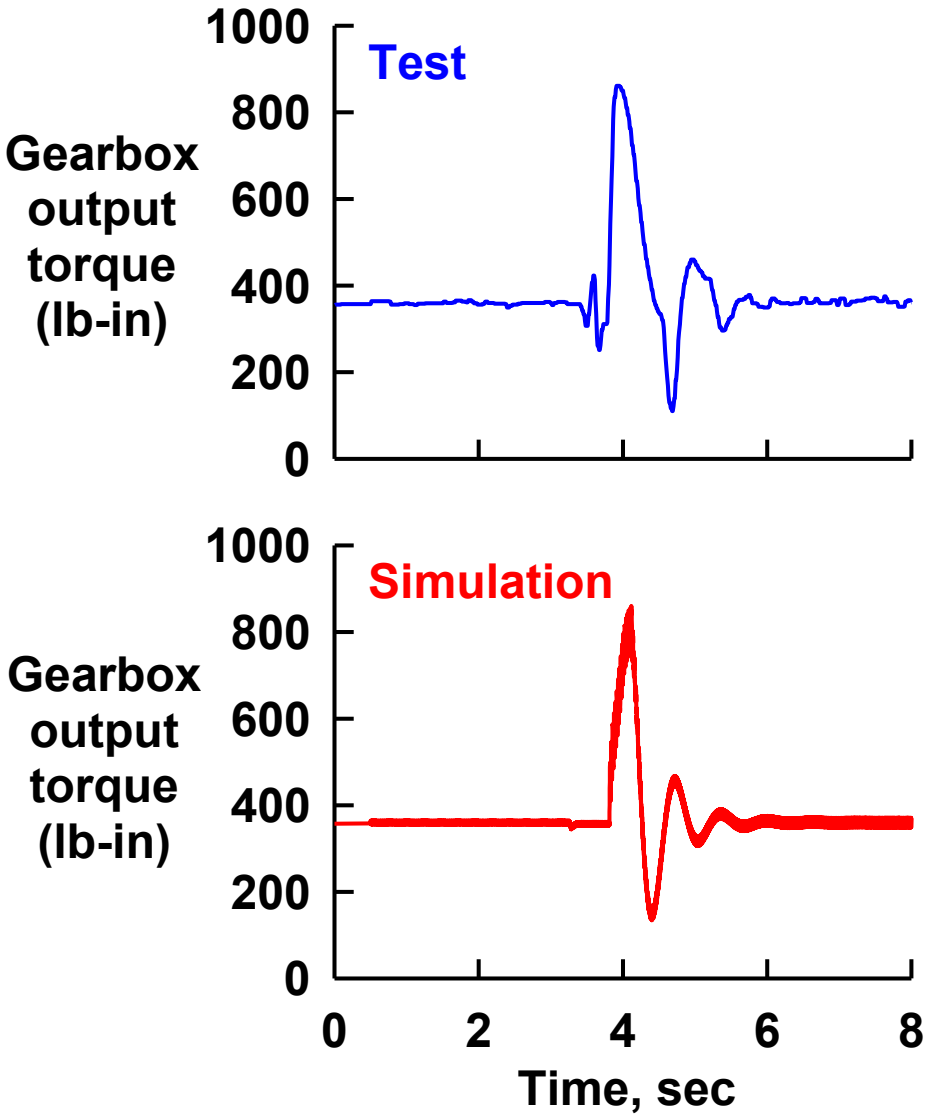






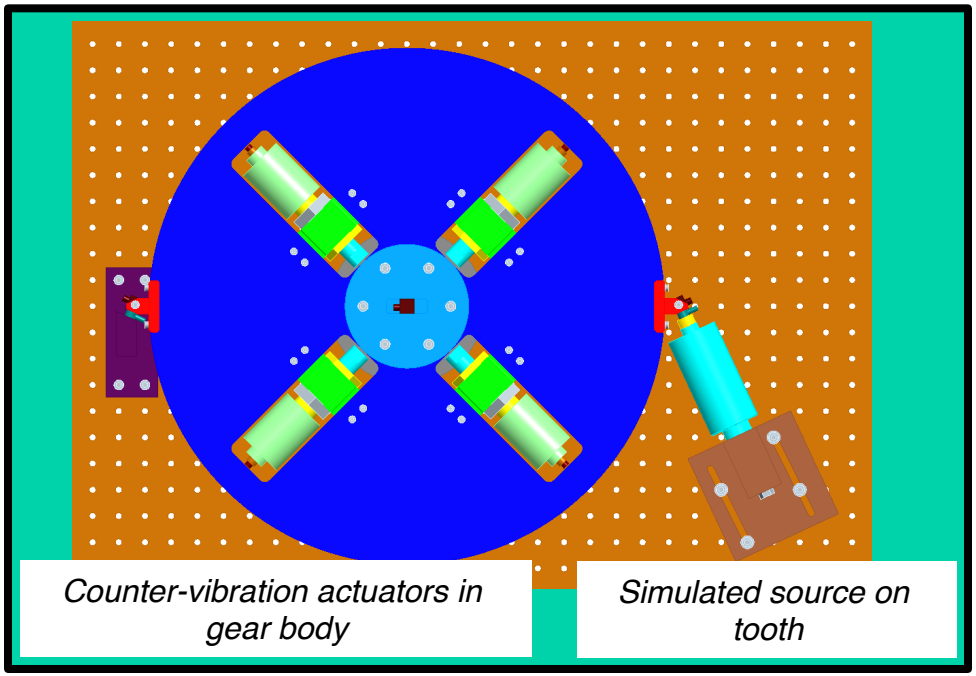
Two-Speed Gearbox Dynamics

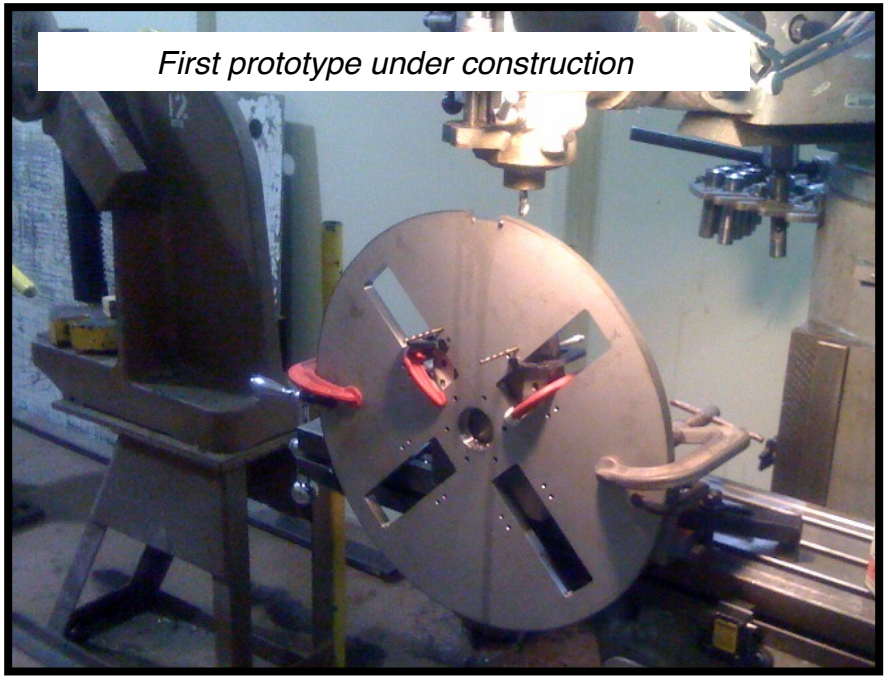




Smart Gear – Feasibility Experiment

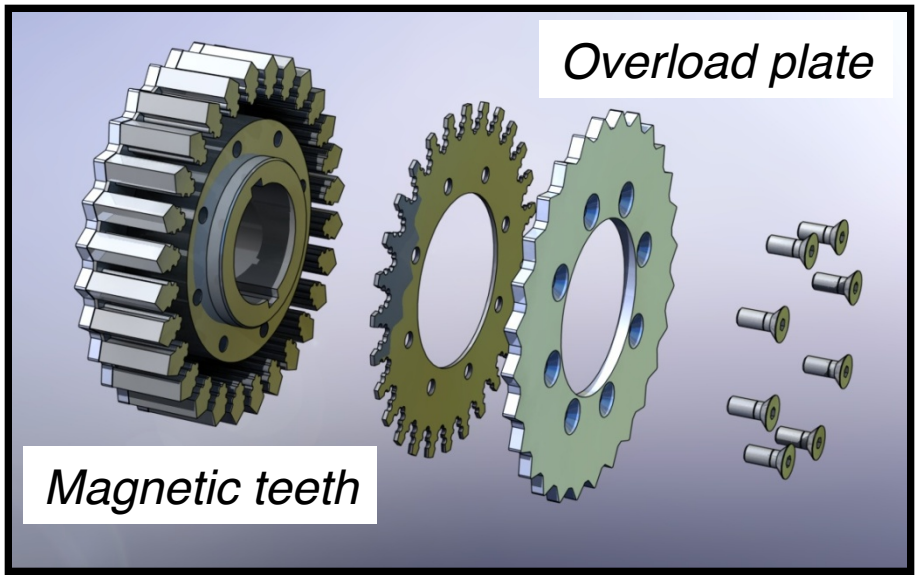
- Mechanical components are beginning to get ‘smart’
  - Future components will have integrated sensors, actuators, and communication.
- To counteract gear induced noise in helicopters, a ‘Smart Gear’ is being developed
  - Noise originates between gear teeth, and takes numerous paths to the cabin.
  - Smart Gear would sense and actively counteract noise at the source.
- Feasibility depends on ability to generate counteracting vibration on a rotating gear

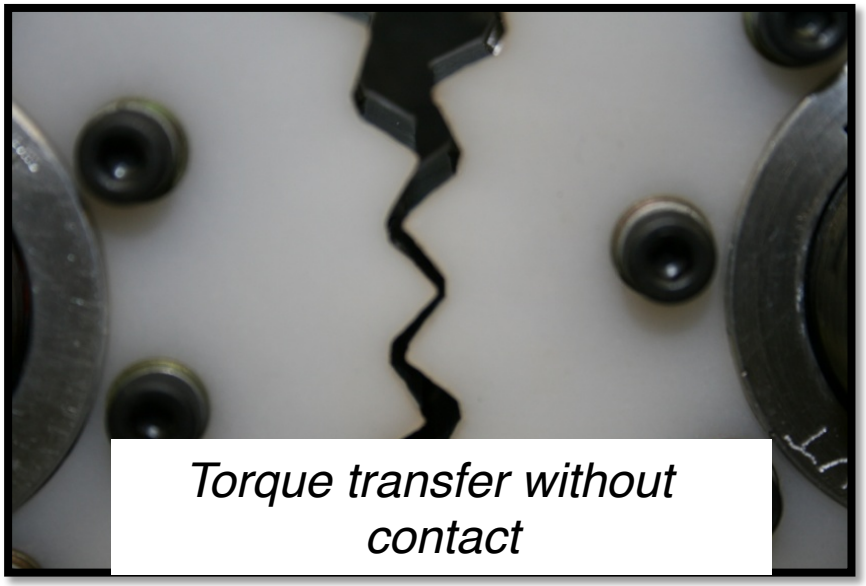




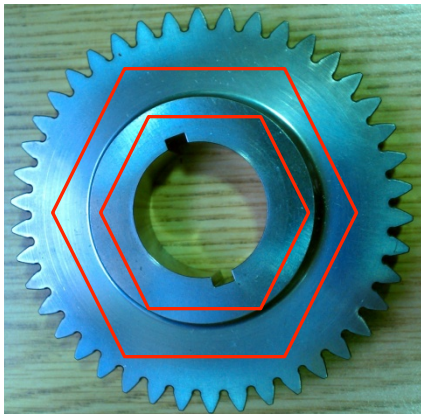
Magnetic gearing – exploratory work

- **Gears create mechanical advantage in the drive system**
  - E.g. Helicopter engine torque is increased by 20x or more
- **Tooth contact generates noise, and failures from wear and heat.**
  - Oil lubrication is needed for gears to survive.
- **Magnetic gearing is being explored to eliminate tooth contact.**
  - Experiments demonstrate that magnetic gears can be virtually silent.
  - Permanent magnets cannot sustain high torque
  - Electromagnetic gears should be explored.

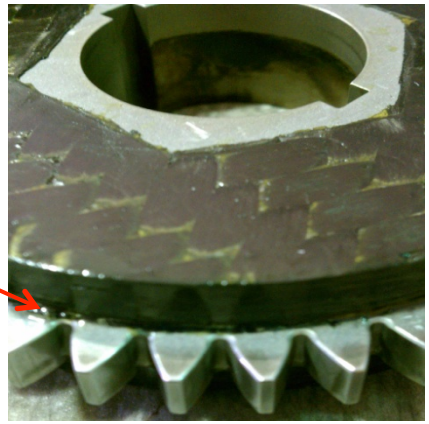


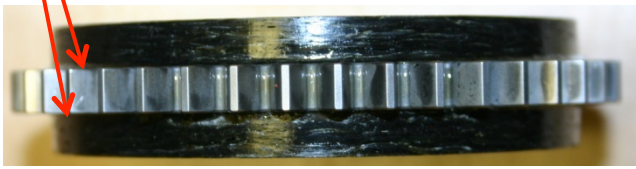


Hybrid Gear



Bonded interfaces

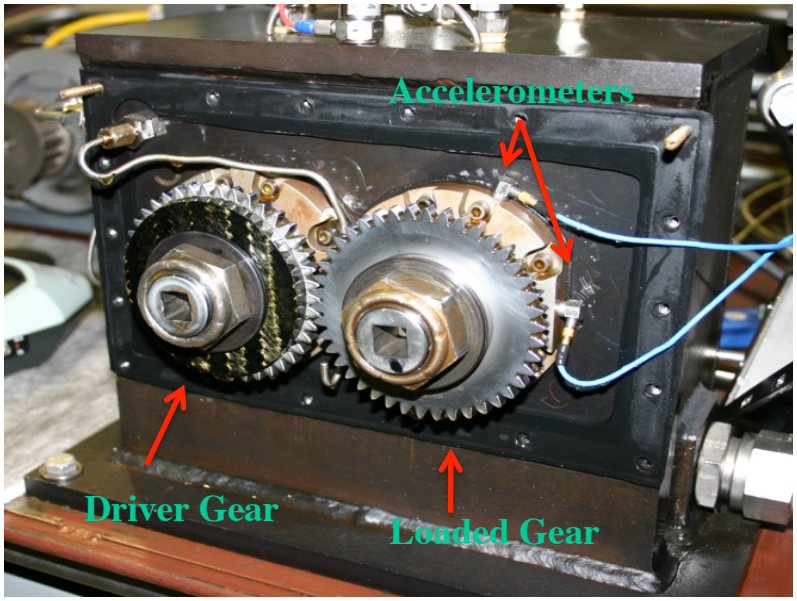


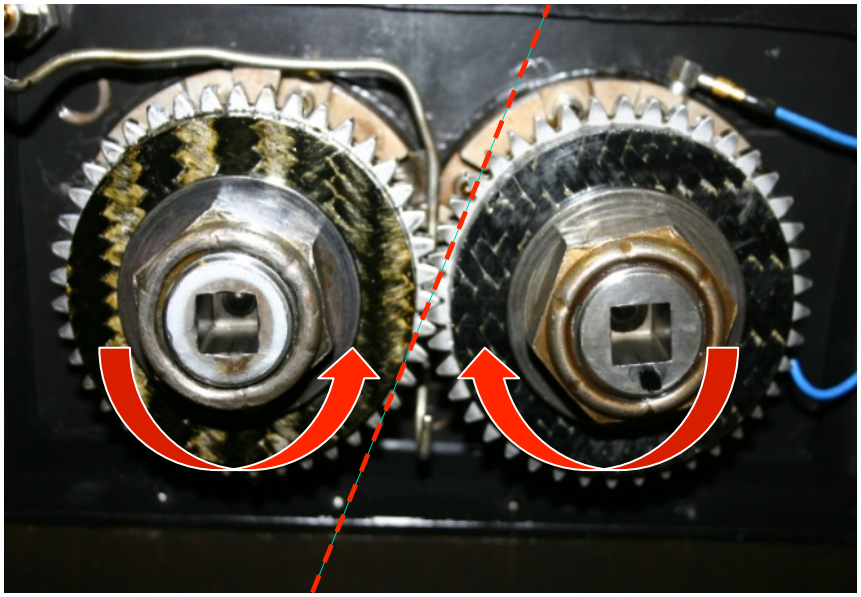


- ***Weight: 0.8847 lbs***
- Machined away steel from web and hub (hexagonal shape).

- ***Weight: 0.7081 lbs***
- Applied 36 layers of the composite system into 3 sections

Hybrid Gear Testing





Status:

- Gears currently undergoing dynamic – fatigue test
- Vibration tests completed
- Processing improvements identified
- Other applications identified

CBM Functions

Propulsion System Health

- Health monitoring of dynamic mechanical components
- Monitored by vibration signature analysis methods (condition indicators-CI) and oil condition

Structural Health

- Fatigue life management/component lifing based on actual usage & regime recognition

Exceedance Monitoring

- Aircraft operational/parametric data (torque, speed, temperature)

Engine Perfromance

- Power assurance check/Power Management

Rotor Smoothing

- Automated track & balance of rotors to decrease vibrations

Fleet Maintenance

- Logging maintenance actions/CBM data

NASA GRC CBM Focus

Propulsion System Health

- Improved detection techniques
- Improved diagnostic algorithms
  - Multi-sensor data fusion
  - Performance metrics
  - Damage magnitude assessment
- Validated methods – rotorcraft field verification
  - Test methods representative of fielded faults
- Future prognostic algorithms
  - Damage life prediction models – predict remaining useful life

Structural Health & Exceedance Monitoring

- Correlate aircraft operational parameters to component life.

Research enabled through Partnerships with the FAA and US Army

- FAA funded Space Act Agreements
- Access to > 2000 Army HUMS equipped helicopters

Propulsion System Health

Planetary Fault Detection

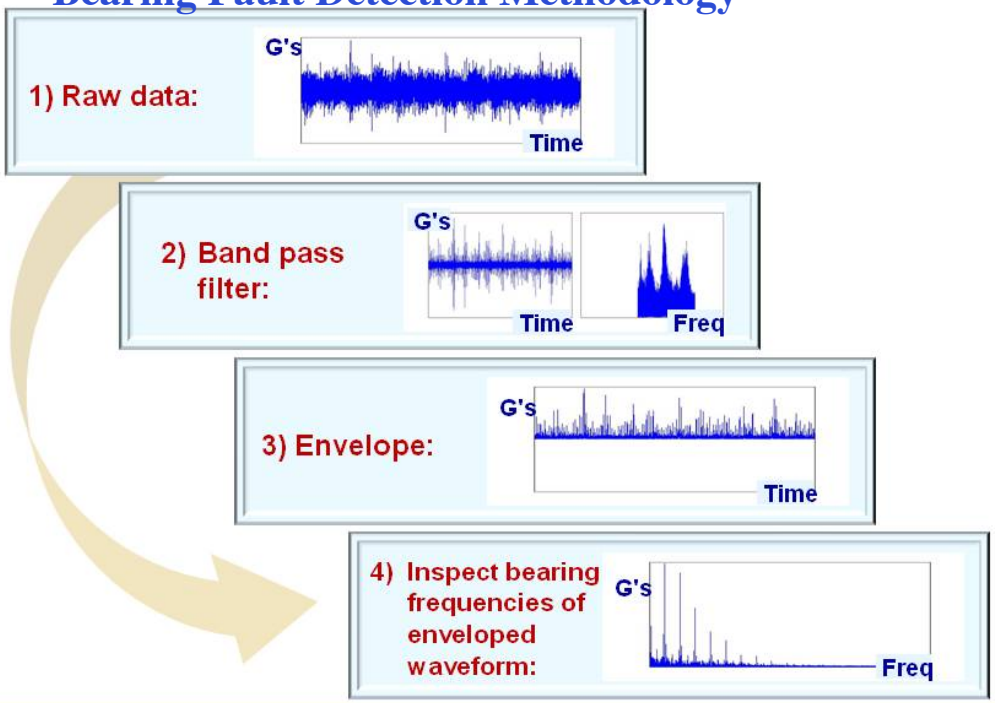
Objective:

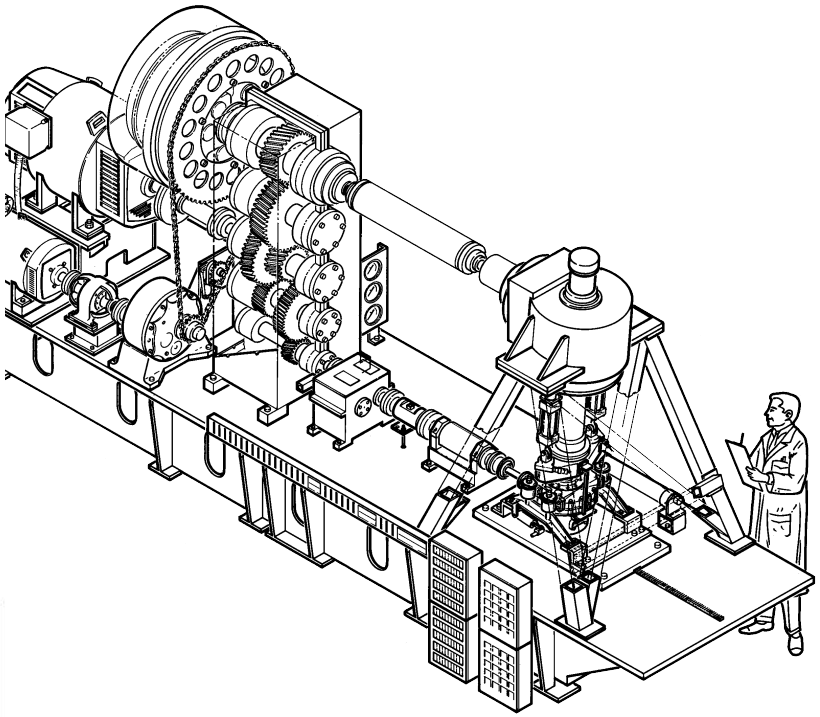
Demonstrate diagnostics to detect gear and bearing planetary system faults in main-rotor gearbox

Approach

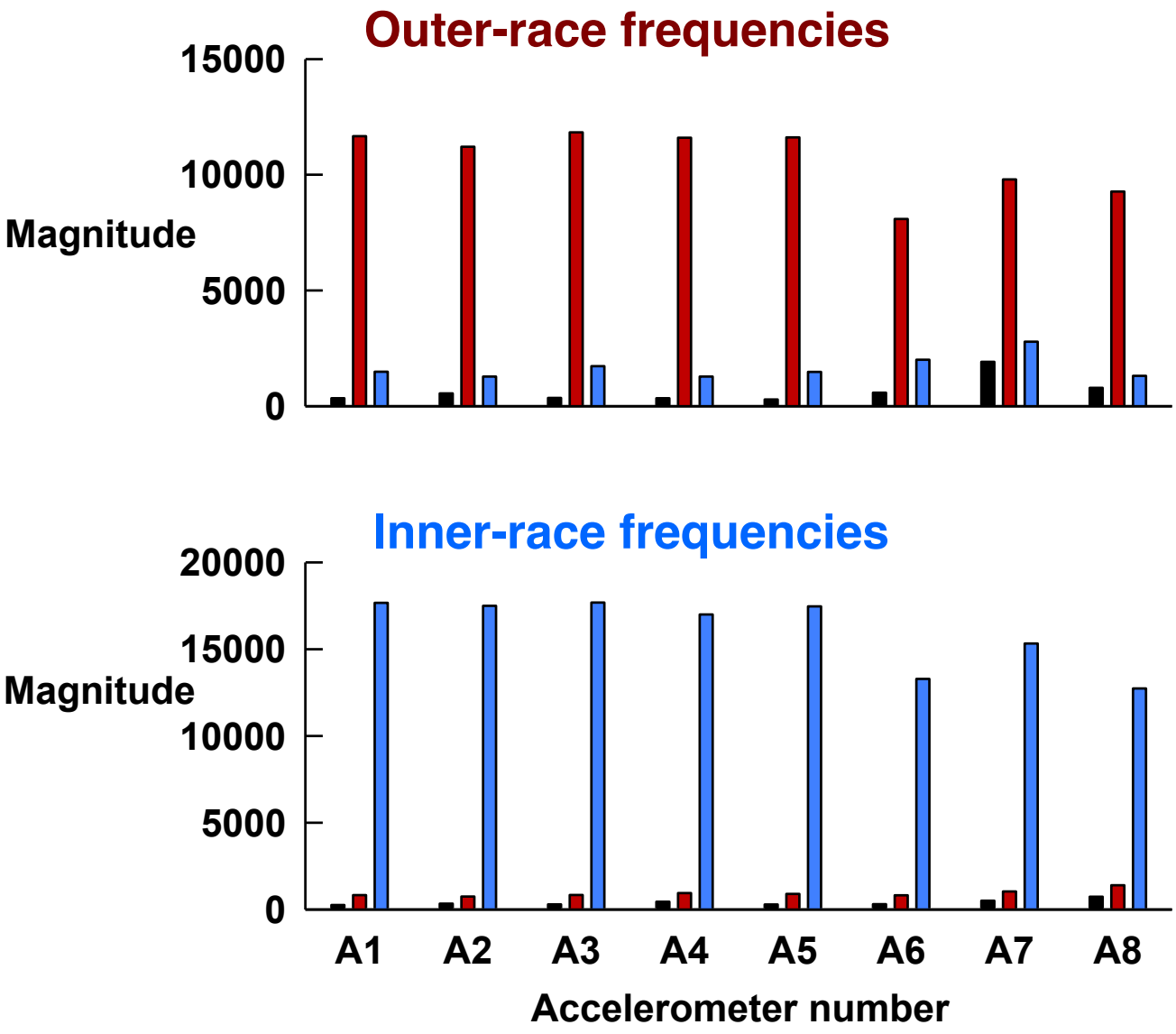
Develop vibration algorithms from seeded fault tests on the OH-58 main-rotor transmission (AATD/Bell OSST)

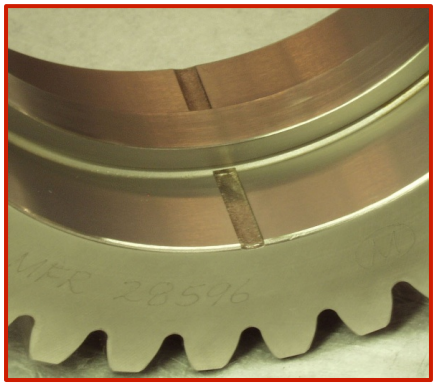
Bearing Fault Detection Methodology





Planet Bearing Fault Detection

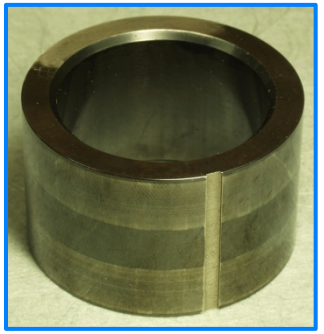




Outer-race defect

Healthy

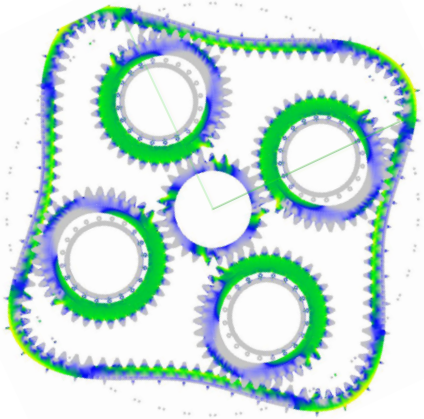
Inner-race defect



Propulsion System Health

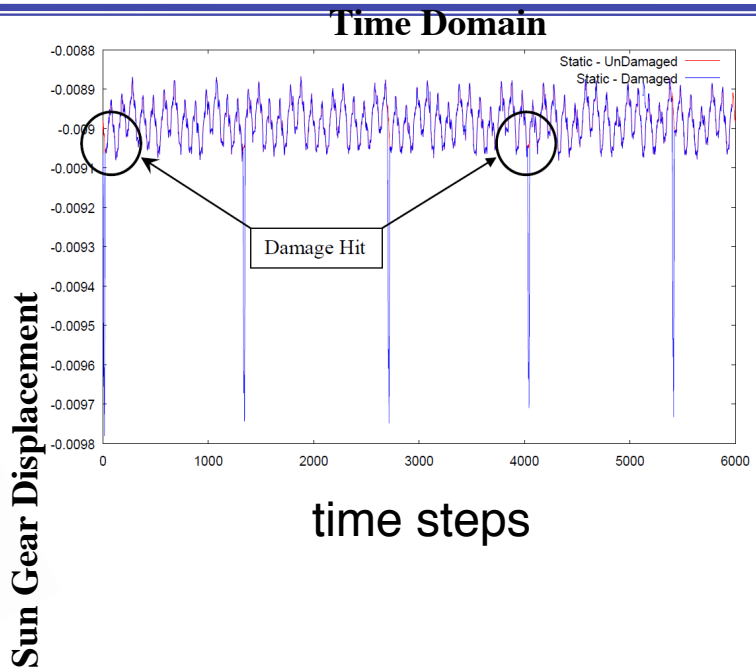
Objective:

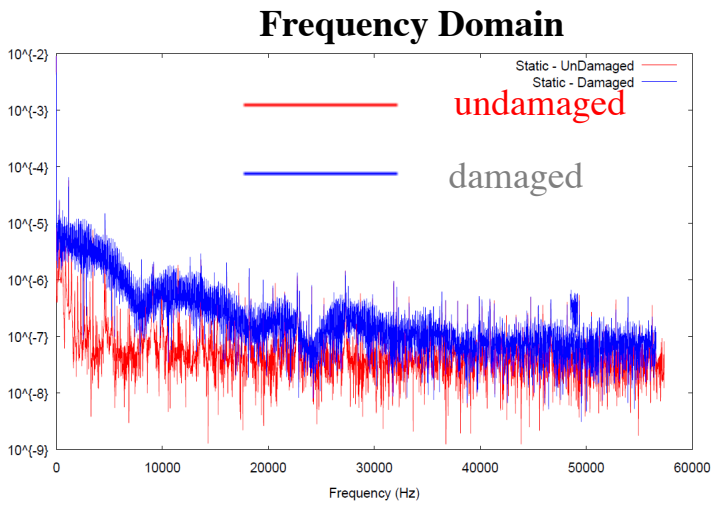
Develop analysis method to simulate dynamic response of gear or bearing surfaces with damage



Approach:

- Defect geometries defined by actual measurements
- Forces between components calculated via contact mechanics
- Deformations and vibration responses calculated via finite element
- Bearing module also available





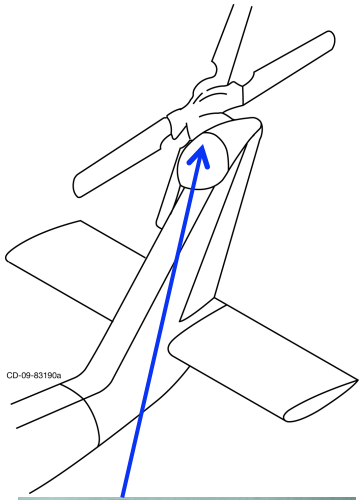
Propulsion System Health

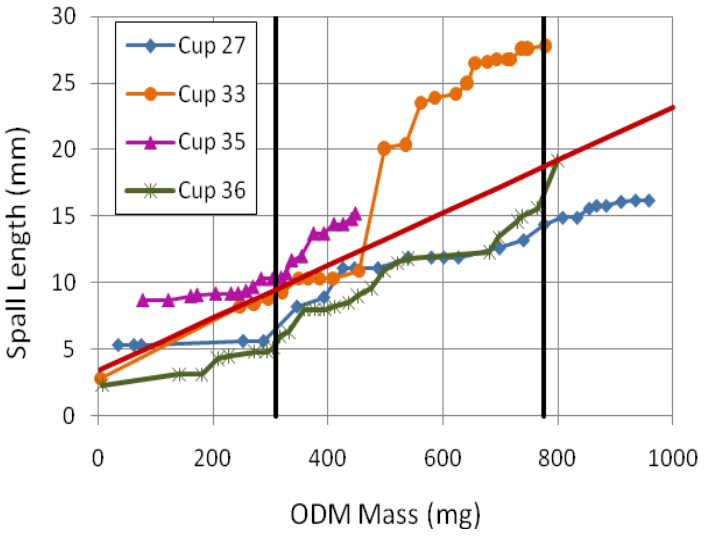
Objective:

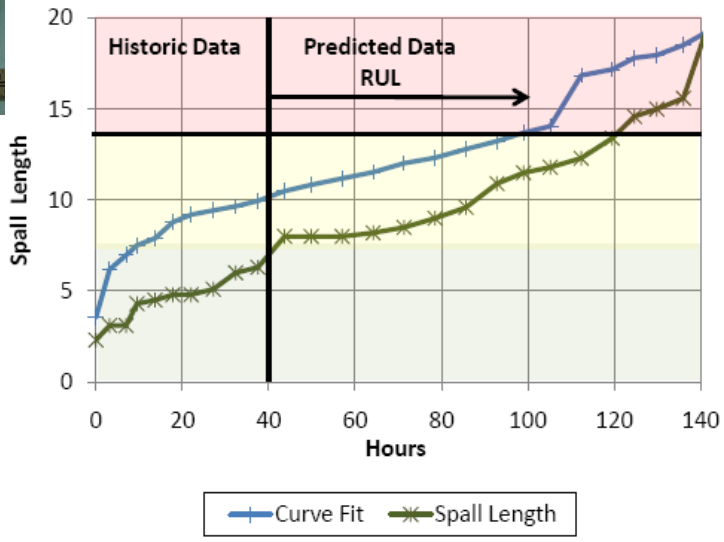
- Demonstrate (CI) responds to failure progression & correlates to remaining useful life

Approach:

- UH60 tail gearbox output shaft thrust bearings
- Removed from helicopters installed in test stand
- Periodic inspections to measure spall growth
- CI data mapped to the damage state did not perform well for magnitude assessment
- Oil debris sensor monitored debris generation & indicated progression & remaining life.







Summary

- Three main R&D focus areas at NASA Glenn:
  - * Advanced Components and Systems
  - * Lubrication Technologies
  - * Condition Based Maintenance
- Currently conduct / manage research within our center as well as at contractor and university locations
- Involved in analytical and experimental developments
- Work closely with the space & aerospace industry, other government agencies / NASA centers, ….